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COMBUSTION AND FLUE GAS ANALYSIS

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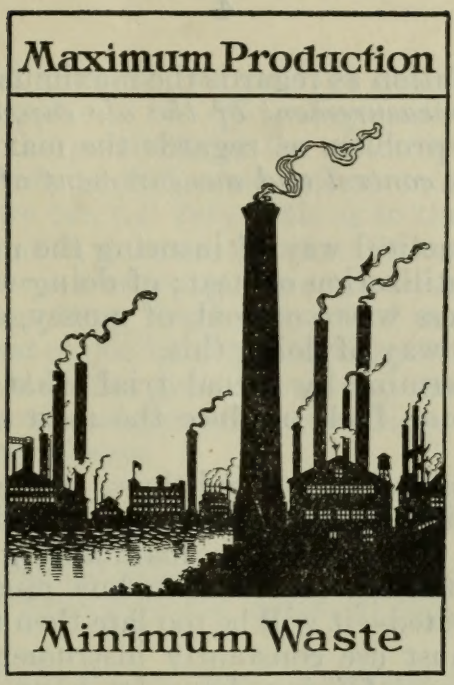

Twenty-five to fifty million tons of coal a year can be saved by the improved operation of industrial power plants without changing their present equipment, and without decreasing their manufacturing output.

In order to save fuel by burning it correctly it is not enough to merely bring about the proper conditions in the furnace. These conditions, after they are once started, must be kept going, and we must have some means of knowing positively that they are being kept up.

The instruments recommended in this bulletin furnish the means of securing this necessary information.

United States Fuel Administration.

COMBUSTION AND FLUE GAS ANALYSIS.

Based on an article by JOSEPH W. HAYS, *Combustion Engineer.*

There is absolutely only one way to stop wasting coal burned in steam power plants.

Part first of this one and only way is to insure that every particle of the carbon of the coal comes in intimate contact with enough heated air to supply $2\frac{2}{3}$ pounds of oxygen [1] to each pound of carbon.[2]

Part second of this one and only way to insure fuel economy is to insure that the maximum proportion of the heat developed produces steam.

To do both of these things is absolutely the only way to make each pound of coal generate all of the steam it can.[3]

To even attempt to do either without the use of the control instrument to be referred to later is simply to waste coal *inevitably*, *invariably*, and *unnecessarily*.

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[1] This weight of oxygen would be contained in 11.5 pounds of air.
[2] In this bulletin carbon will be considered to be the only combustible component of coal.
[3] Practically the highest desirable temperature will depend largely on the fusing point of the ash.

The key to the solution as regards the maximum *production* of heat is the *control and measurement of the air supplied to the furnace;* the solution of the problem as regards the maximum *utilization* of heat is found in *the control and measurement of the temperature of the flue gases.*

Now, as to the practical way of insuring the maximum production and the maximum utilization of heat; of doing what we simply *must* do to avoid a needless waste of coal, of money, of time; again there is one *indispensable* way of doing this.

1. You must determine by actual trial what conditions in *your* furnace, burning *your* fuel, produce the most steam per pound of coal.

2. Having determined these conditions, you must employ *continuously* methods which will maintain these conditions or which will show you *promptly* that you are *not* maintaining them. You can not wait till the end of the day to determine how much steam power each pound of coal generated—it will be too late then to recover coal needlessly lost. You must use constantly instruments which will show you that you are *maintaining*, hour by hour, minute by minute, conditions in your furnace and boiler which you had previously *proven* insured a maximum production of steam per pound of fuel and a maximum *saving* of heat developed.

The instruments which are absolutely indispensable to an efficient furnace control, without which fuel waste is inevitable, are flue gas analysis apparatus, pyrometers, and draft gauges. The first instrument detects and determines excess air; the second measures the heat lost in excess air; and the third tends to prevent excess air.

WHY SOME EXCESS AIR IS NECESSARY.

As we have seen, a proportion of about 11.5 pounds of air to every pound of carbon in coal is the amount necessary to insure the development of all the heat of the fuel and this full amount *must actually come in contact with the fuel*—as, however, in the rapid passage of air through a furnace, some of it never reaches the fuel, an excess of about 40 per cent [1] above the amount of air which contains the oxygen required should be used.

WHY AN UNNECESSARY EXCESS OF AIR IS VERY WASTEFUL.

A pound of carbon can not possibly combine chemically with more than $2\frac{2}{3}$ pounds of oxygen. Therefore to use more than the minimum excess of air necessary, *under furnace conditions*, to insure this proportion, is simply to provide in this needless excess a vehicle for the transfer of heat to the stack.[2] Any heat which reaches this point is lost, and just to the extent to which you allow heat to reach the stack in an unnecessary amount, just to this extent do you render *absolutely null and void* all the care employed in the generation of the maximum amount of heat.[3]

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[1] The true percentage depends largely on whether the carbon is in the solid form and is burned on the grate or in the form of gas (under furnace conditions) burned in the combustion space.

[2] A larger mass of air to be heated means a lower temperature in the gases passing over the boiler tubes. It also means a greater velocity of the gases; both reduce the ratio of heat absorbed to heat generated. The result is increased stack losses.

[3] The rule to be followed in controlling the air supply is "Generate from every pound of coal all of the CO_2 you can without producing any CO and without fusing the ash."

What has been said above shows that *the control of the air supply is absolutely indispensable to the efficient operation of a furnace.*

But both air and the products of the chemical union of air with carbon (carbon dioxide or CO_2 and carbon monoxide or CO) are invisible,[1] therefore we can tell very little as to the air being supplied a furnace by looking at it, or even into it; still less can we judge as to the heat which a boiler is absorbing if we use the eye alone.

Enormous losses resulting from the use of needless excess of air may occur, in the vast majority of plants do occur, and will *inevitably* occur unless by the use of flue gas analysis and temperature and draft control we establish and *maintain* such conditions in the furnace that effectively prevent these losses.

HOW FLUE-GAS ANALYSIS DETECTS EXCESS AIR.

Suppose we fill a vessel whose interior volume is, say, 30 cubic inches, with flue gas, take 15 cubic inches of this and determine the CO_2 in it.

Assume the CO_2 to be 10 per cent. Suppose we next add to the 15 cubic inches of gas remaining from the *original* sample enough air to make its volume again 30 inches; take 15 cubic inches of this diluted gas and determine the CO_2 in this. We will, of course, find this to be 5 per cent, for, as the 30 cubic inches of the diluted gas has only as much CO_2 as 15 cubic inches of the original gas, it is half as strong (in CO_2) we might say; that is, its percentage of CO_2 has been reduced by one-half.

Now, the effect on the composition of the gas will be *in general terms* the same if the dilution occurs *in the furnace* through the admission of excess air.

As a pound of carbon can never produce more than $3\frac{2}{3}$ pounds of carbon dioxide, the more air we add to this in the furnace the poorer in CO_2 will the furnace gas become, so that by determining the CO_2 in the flue gas we measure with more or less accuracy the air supplied to the furnace in successive hours.

Having determined what percentage of CO_2 produces maximum steam production in a given furnace burning a certain fuel, we have in flue-gas analysis an *invaluable, indispensable* means of maintaining these conditions.

WHY THE USE OF A PYROMETER SAVES FUEL.

In making every pound of coal develop all of its heat we take a long step toward preventing fuel waste, but if we stop here we will never insure maximum combustion efficiency.

Unless we get a maximum proportion of this heat into the boiler water, we inevitably burn more fuel than is absolutely necessary to generate a pound of steam. The larger the percentage of heat absorbed by the boilers the smaller the percentage of heat lost through the stack, and the only possible way to know what proportion of heat is going to form steam is to have a *continuous* record of the temperature and amount of the flue gas.

The pyrometer is the means of securing this indispensable data on temperature.

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[1] Even CO is in the diluted form in which it occurs in a furnace.

Maximum heat production in the furnace combined with maximum heat absorption in the boiler produce maximum furnace and boiler efficiency. To fail to secure either is a disgrace to anyone who operates a power plant.

To strive to secure both is *an imperative duty that you owe your country*—simply a recognition of what you owe *yourself*.

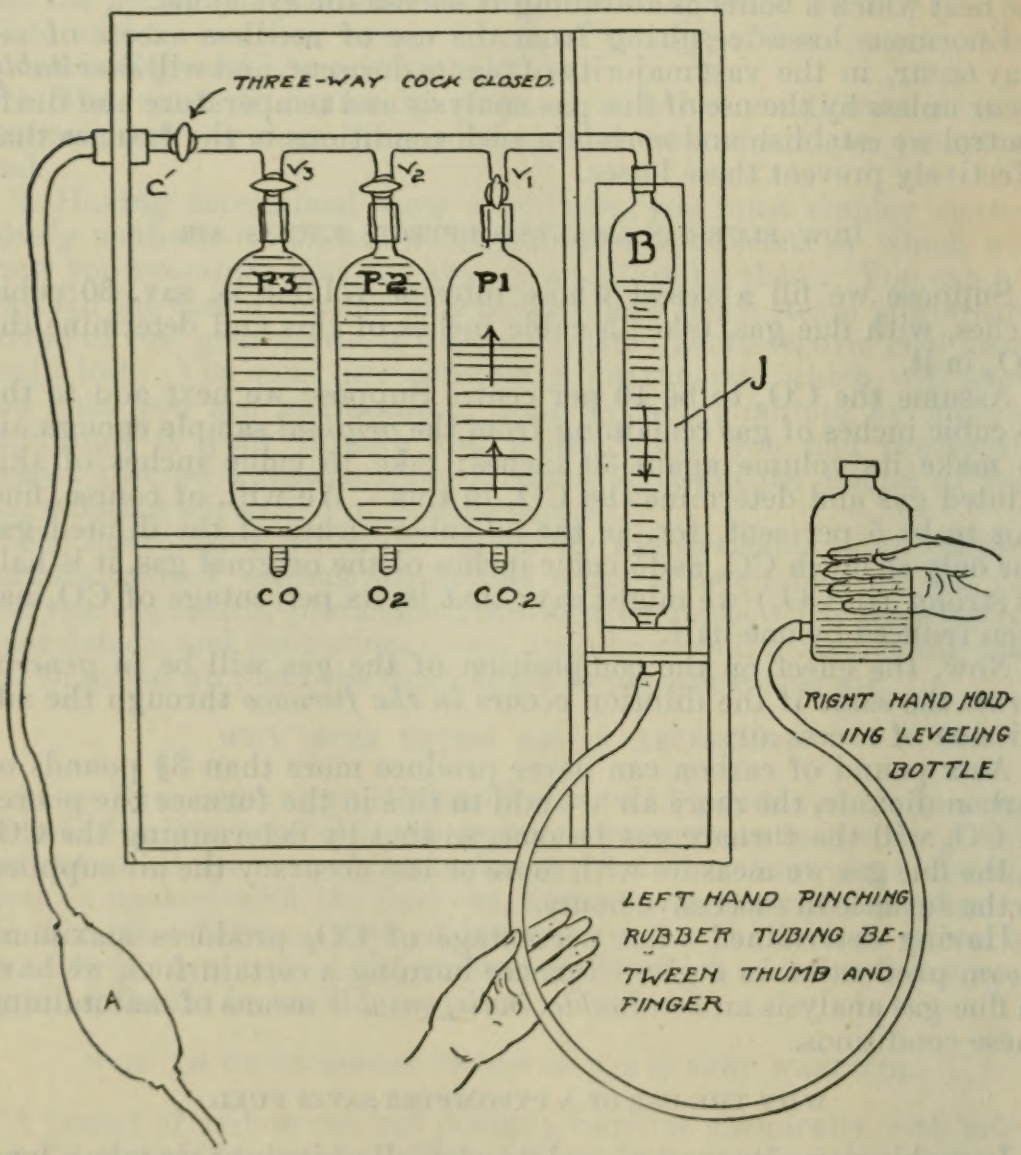

FIG. 1.

COMBUSTION-CONTROL APPARATUS.

General instruction as to its use.

A. *Gas-analysis instruments.*—The gas-analysis apparatus most frequently used is some form of the various types of "Orsat" (see fig. 1). The direction for its use, which may be secured from the dealer, are so explicit that skill in its use is acquired within an hour or two.

It enables one to determine CO_2, O_2 (oxygen, a measure of the air supply), and CO in 15 to 30 minutes. *No investment in power-plant*

equipment will pay a higher rate of interest than will a well-used gas-analysis apparatus.

Of gas analysis it may be said as of all other analyses that it is a worse than useless process unless the particular portion of material analyzed represents the average composition of the larger mass from which the sample is taken.

"A" in figure 2 shows the correct location of the sampling tube at the point where the gases leave the boiler, as near this as possible, and where the velocity of the gas stream is a maximum. "B" shows an uncorrect location.

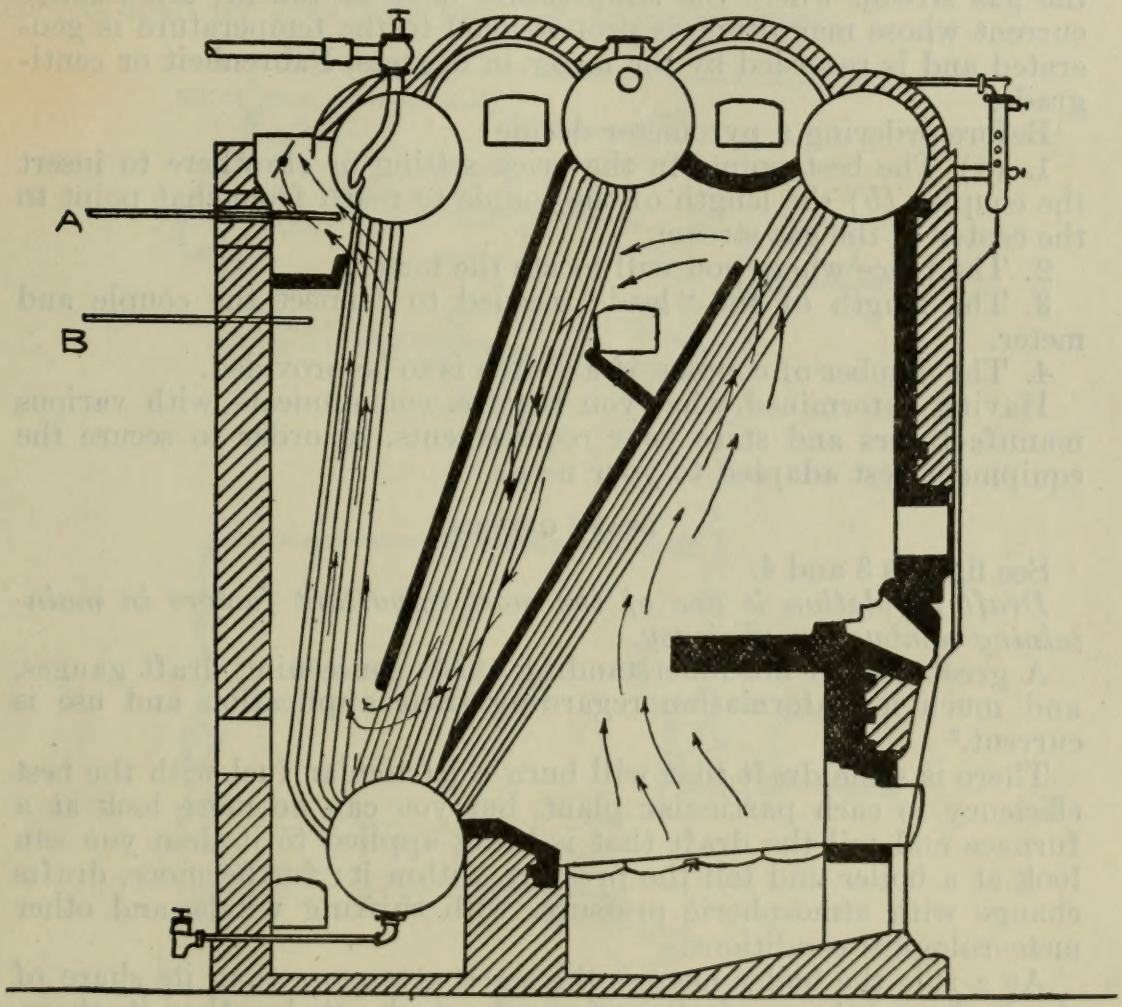

FIG. 2.

The sampling tube should be a $\frac{1}{8}$ to $\frac{1}{4}$ inch iron tube inserted into the center of the gas stream. Under no circumstances should a perforated pipe, a nest of pipes, a "spider," or any similar device be used.[1]

PYROMETERS.

In order to determine the preventable heat loss from excess air it is necessary to know not only the volume but also the temperature of the excess volume.

[1] For special directions see Bureau of Mines Bulletin 97, "Sampling and Analysis of Flue Gases."

The temperature should be taken at the same point as the sample of gas for analysis; that is, *at the point where the gases leave the heating surfaces of the boiler*, and is best determined by means of some form of pyrometer, either of the mercurial, expansion, or electric type. The latter is probably preferable because of its greater convenience.

The essential parts are a "couple," which consists of two wires, usually of some special alloy, welded together, and an indicating or recording meter, connected by insulated copper wire to the couple.

To determine the temperature of the gas the couple is inserted in the gas stream where the temperature is to be taken. An electric current whose magnitude is proportional to the temperature is generated and is recorded by the meter in degrees, Fahrenheit or centigrade.

Before ordering a pyrometer decide:

1. (*a*) The best points in the brick setting or elsewhere to insert the couple; (*b*) the length of the couple to reach from that point to the center of the gas stream.
2. The place where you will locate the meter.
3. The length of the "lead" needed to connect the couple and meter.
4. The number of couples, if a switch is to be provided.

Having determined what you require, communicate with various manufacturers and state your requirements, in order to secure the equipment best adapted to your needs.[1]

DRAFT GAUGES.

See figures 3 and 4.

Draft regulation is one of the most important factors in maintaining combustion efficiency.

A great deal of misunderstanding exists concerning draft gauges, and much misinformation regarding their application and use is current.[2]

There is some draft that will burn a particular fuel with the best efficiency in each particular plant, but you can no more look at a furnace and tell the draft that is being applied to it than you can look at a boiler and tell the pressure within it; furthermore, drafts change with atmospheric pressure, with shifting winds, and other meteorological conditions.

As a rule the boiler nearest the stack gets more than its share of the draft, and the one farthest from the stack gets less than its share, depending on the flue connections. Many serious cases of draft troubles could be cured and fuel saved by adjusting the individual dampers to equalize the draft among the boilers. After equalizing, the drafts of all may be changed at once by using the main breechings damper.

THE BEST DRAFT TO USE.

You should use the draft that will meet the load conditions and produce the best percentage of CO_2 without CO and without fusing the ash. There is practically no exception to this rule.

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[1] For extended directions see Bureau of Mines Bulletin 145, "Measuring the Temperature of Gases in Boiler Settings."

[2] For special discussion see Bureau of Mines Bulletin 21, "The Significance of Drafts in Steam Boiler Practice."

As has been stated already, though, the maximum practical furnace temperature depends largely on the fusing temperature of the ash of the coal used; if ash slag forms under the normal of good furnace practice, the obvious remedy is to change the furnace, the fuel, or both.

The best draft over the fire for hand-fired furnaces burning bituminous coal ranges from 25 to 40 hundredths of an inch of water (the scales of most draft gauges are calibrated in terms of water displacement), but it may be materially more or less, depending on the grate used, the size and ash contents of the fuel, etc. Find out the correct draft for *your* plant by using the gas analyzer.

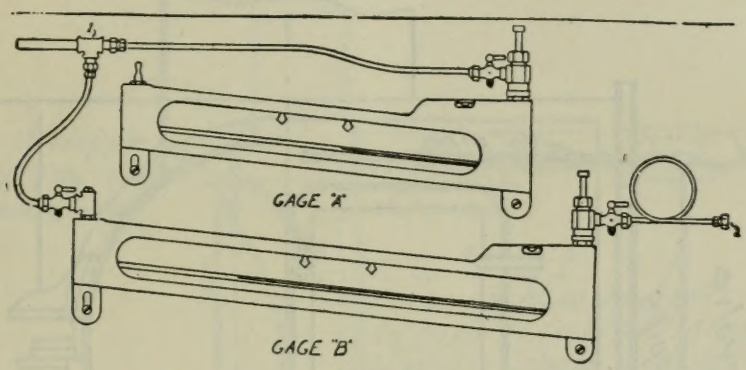

FIG. 3.

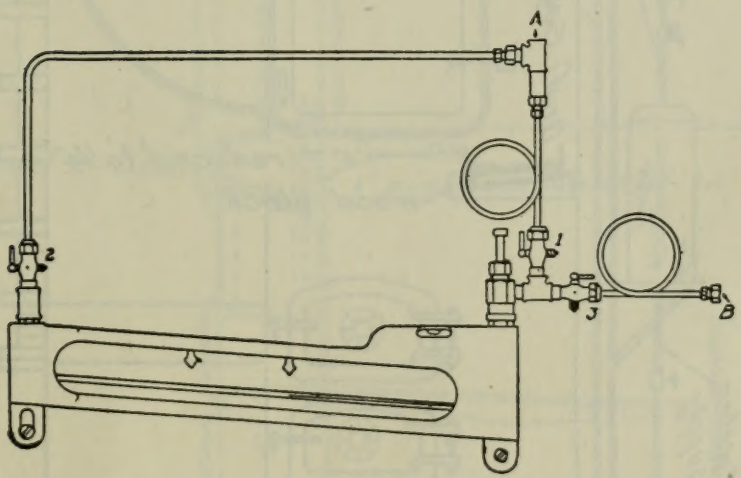

FIG. 4.

It is not necessary, except for purposes of special study to take the draft at any point except the furnace, but it is essential to have a constant indication of the draft there.

The gauge should be so located that it will be before the eyes of the fireman. An experienced fireman will fire by the draft rather than the steam gauge.

Figure 3 shows a combination of two draft gauges; figure 4 a single one with special connections. Figure 4 is probably the more practical—it will not confuse the fireman.

If desired, the draft drop through the boiler may be read at any number of points by installing the necessary pipes and cocks. A study of the diagram with attached explanation will make the manner of installing and the method of use apparent.

POINT AT WHICH TO INSTALL DRAFT GAUGE.

In installing the draft gauge a point in the furnace wall, in front, should be selected as far above the grates and as near the front of the furnace as possible. Figure 5 shows an approved method of connecting and mountaing a draft gauge on a horizontal return tubular boiler, also an improved method of installing a gas collector.

Draft gauge "A" in the above diagram is connected to show the draft over the fire. Gauge "B" is connected at the last pass of the boiler and shows the draft drop or loss between the last pass and the furnace.

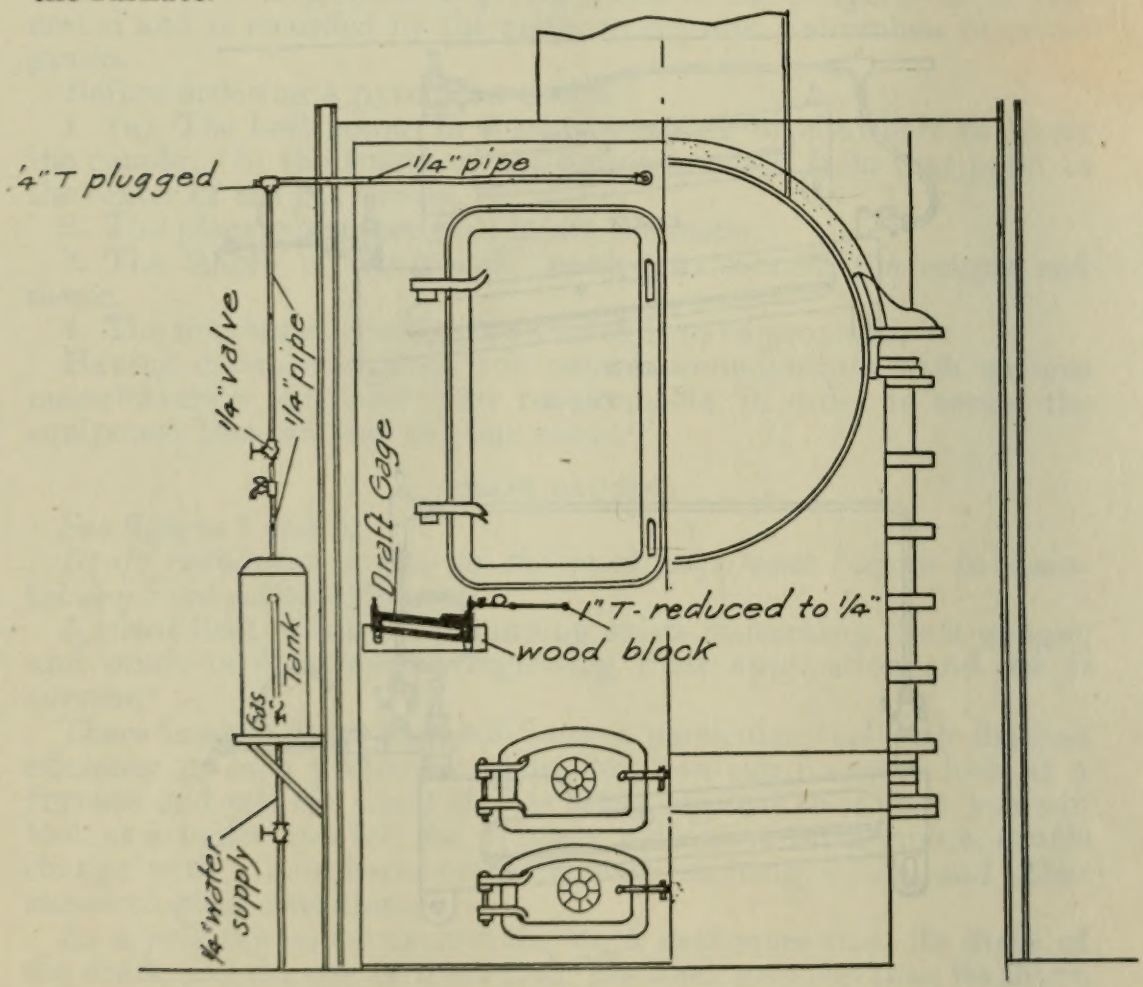

FIG. 5. Front.

The draft gauge (fig. 4) is normally used to show the draft over the fire, but it may be used to take any of the readings obtainable in the combination, figure 3. "A" (fig. 4) is connected at the furnace and "B" at the last pass.

(*a*) To read draft over fire: Open valve 1, close valve 3, and set valve 2 to atmosphere.

(*b*) To read draft in last pass: Open valve 3, close valve 1, and set valve 2 to atmosphere.

(*c*) To read draft loss between last pass and furnace: Open valves 2 and 3 and close valve 1.

INTERPRETATION OF DRAFT GAUGE READINGS.

To interpret the gauge readings, there are a few principles to remember. *If the liquid moves toward the zero point of the scale at the left the fires need attention; they are burining thin*, or holes are forming in them. If the liquid moves in the other direction, the fires are thick and should be burned down or perhaps raked before adding more coal.

Locate all gauges where the fireman can watch them most readily and place the damper control so that he can observe the draft gauge while setting the damper.

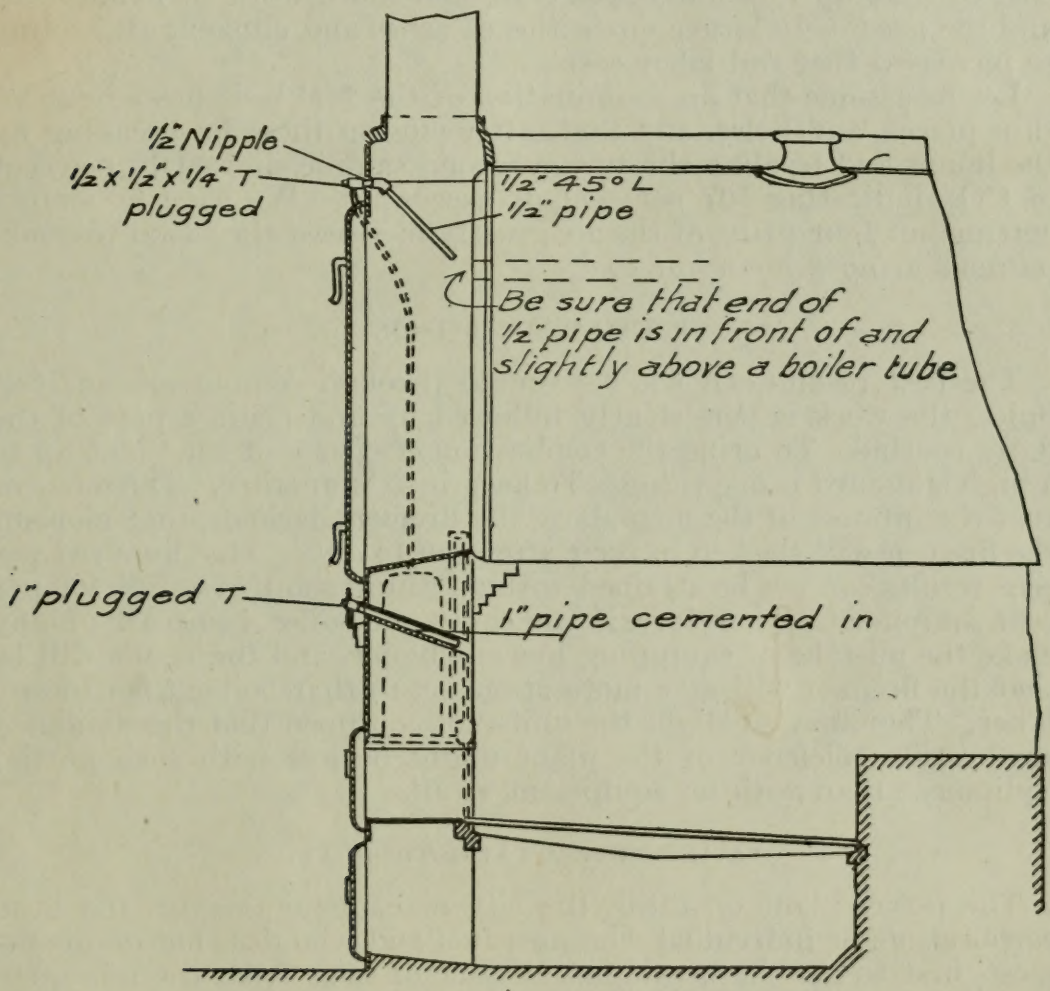

FIG. 5. Section.

The plant owner should see that the uptake damper can be adjusted easily from the front of the boiler, otherwise the fireman can not be blamed for using the wrong method. He should be made to use the dampers instead of the ash pit doors. If he does not, the doors might be removed.

NECESSITY OF INSTRUCTIONS TO FIREMEN, ETC.

A very important part of the measure that may be found necessary to improve the efficiency of a power plant will be instructing the fireman as to the effects of opening the furnace doors unnecessarily

often or of leaving them ajar, of leaky boiler settings, of holes or cracks in the fuel bed, of too much or too little draft, etc. Encourage the firemen to ask questions and instruct them largely through your answers to these.

Explain that the gas-analysis apparatus is really an instrument for determining whether or not an excess amount of air (which means more work for him) is flowing over the boiler heating surface. Let him watch while a gas sample is being drawn and then analyzed.

Assuming that the sample shows 4 per cent of CO_2, explain that this means that the furnace is taking at the rate of 517 cubic feet of air where it should be taking only 140; that this excess means more coal to heat up this unnecessary air and more work to handle this and the *needlessly* larger quantities of ashes and clinker; all leading to increased fuel and labor costs.

Let us assume that an examination of the fuel bed showed cracks, thin places, and holes, and that, after closing these by breaking up the lumps and leveling the fuel, a second sample showed 10 per cent of CO_2, indicating 107 per cent of excess air. We have by simply cutting out four-fifths of the air greatly increased the steam pressure *without firing a pound of coal.*

ROUTINE SUPERVISION.

The best results can not be secured through combustion analysis unless the work is persistently followed up and made a part of the daily routine. To bring the combustion efficiency of the plant up to a high standard is one thing. To keep it so is another. The moment that the interest of the men above the firemen slackens, that moment the firemen will slacken in their attention to duty. One hundred per cent results can not be attained with anything short of a full 100 per cent equipment. Therefore, if you equip one boiler, equip all. Many make the mistake of equipping but one boiler, and the result will be that the firemen will give more attention to that boiler than to any other. They may so slight the units not equipped that the combined combustion efficiency of the plant might be less with such partial equipment than with no equipment at all.

SAVING FUEL A PATRIOTIC DUTY.

The power-plant operator, the city manager or mayor, the firm, corporation, or individual who uses fuel and who does not do his utmost, first to get the maximum amount of heat from the minimum amount of combustible and then to save the maximum amount of this for steam productions, fails to assume an obligation which the needs of his country impose upon him, and which should be discharged both as a patriotic duty and as a means of promoting his own interests.

This bulletin explains how this imperative duty of saving fuel may be most effectively performed.

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